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(54) MEASUREMENT OF CARBON DIOXIDE IN A GAS WHICH IS TO BE INHALED.

(71) We, DRAGERWERK AKTIENGESELLSCHAFT, a Germany body corporate of 2400 Lubeck, Moislinger Allee 53/55, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a device for monitoring the carbon dioxide concentration in a gas mixture which is to be supplied to a patient, e.g. for inhalation anaesthesia.

In our earlier Patent Application No. 21142/70 (Serial No. 1,314,877), there is described and claimed an apparatus for measuring the concentration of carbon dioxide in gas which is to be inhaled by a patient, which apparatus comprises a cell the wall of which includes at least one area which is gas-permeable and liquid-impermeable and which cell includes two electrodes immersed in deionized water, wherein the inner surface of the or each area which is gas-permeable and liquid-impermeable is in contact with the deionized water and the outer surface thereof is such that, in use, it can be contacted by the gas which is to be inhaled by the patient.

In one embodiment of our earlier invention, the measuring cell may be held by two flexible tubes in the wall of the pipe which forms the outlet of an absorber containing a filling of soda lime and which conducts the anaesthetising gas mixture issuing from the absorber to the patient's breathing mask. The essential function of the cell membrane is that it only allows the passage of the gas mixture from the pipe to the very small volume of water, whereas at one side any water droplets issuing from the absorber, and in which residues of soda lime may be dissolved, are retained within the pipe and at its other side the deionized water is retained within the cell interior. As soon as the electrical measuring instrument connected to the electrodes indicates that the deionized water has taken up a certain proportion of carbon dioxide from the anaesthetising gas mixture of the pipe, the cell contents, i.e. the small quantity of water in which the carbon dioxide measured is dissolved, and at which measurement was carried out, has to be replaced by a new small quantity of deionized water in order that a smaller carbon dioxide concentration than that measured previously can be detected at the measuring instrument. For this purpose a pump may be connected to the flexible tube issuing from the pipe wall and a container containing an ion exchanger may be connected to the other flexible tube. The pump conveys the small quantity of water enriched with carbon dioxide to the container with the ion exchanger, from which deionized water is subsequently taken and conveyed back to the cell so that it can again receive carbon dioxide from the anaesthetising gas mixture flowing in the pipe, through the diaphragm, and can make the electrical measuring instrument give an indication.

In order not to have to interrupt the indication of the carbon dioxide concentration in a gas mixture by a pumping operation, it is known from the British Patent Specification No. 1,143,403 to provide a closed water circuit in which there are arranged on the one hand the measuring cell and on the other hand the container with the ion exchanger. The gas mixture, which contains the carbon dioxide to be measured, is forced into the deionized water issuing from the ion exchanger at the lower end of a tube and rises in bubbles with the assistance of gravitational force within the tube until it enters the measuring cell at the upper end of the tube. Owing to this upward movement of the gas bubbles the water is driven in a circuit through the ion exchanger and the measuring cell, the water being continually renewed within the cell and the connected electrical measuring instrument being capable of indicating each instantaneous value of the carbon dioxide concentration.

However, the gas mixture to be supplied to a patient, e.g. for inhalation anaesthesia, cannot be used for driving a quantity of

water since it is finally up to the patient to apply the pressure, e.g. against the water column in the tube, which drives the water through the circuit containing the ion exchanger. A patient cannot reliably be expected to provide this pressure load during breathing. Also, with the known arrangement, difficulties occur in keeping the anaesthetising gas mixture, which issues from the absorber which is filled with soda lime, free of slight impurities such as water droplets in which small quantities of alkali may be dissolved and which, in the absence of the separating membrane, would give rise to a measurement additional to that due to the concentration of the carbon dioxide in the cell and would thereby falsify the measurement of the carbon dioxide content.

According to the present invention, there is provided a device for measuring the concentration of carbon dioxide in a gas mixture which is to be inhaled by a patient, which device comprises a cell the wall of which includes at least one area which is gas-permeable and liquid-impermeable and which cell includes (a) two electrodes which, in use, are immersed in deionized water and (b) an ion exchange material located at a position remote from the or each area which is gas-permeable and liquid-impermeable, wherein the inner surface of the or each of said areas is in contact with the deionized water and the outer surface of the or each of said areas is such that, in use, it can be contacted by the gas which is to be inhaled by the patient, and wherein one of said two electrodes is positioned between the or each of said areas and the ion exchange material and is insulated from said ion exchange material.

The or each area which is gas-permeable and liquid-impermeable can consist of a membrane made of a plastics foil.

Since normally ion exchange resins which are electrically conductive will be used as the ion exchange material, the other electrode can, in one embodiment of the invention, be formed of the mass of ion exchange resin itself.

The ion exchange materials, e.g. resins, used preferably consist of a large number of small particles; and the ion exchange mass can be limited to a portion of the cell interior by means of a fabric, e.g. of a plastics material, whose mesh width is smaller than the particle size of the ion exchange material.

In cases where the ion exchange resins used are not to be or cannot be employed for conducting electrical current, a further electrode can be arranged between the first electrode and the mass of the ion exchange resin.

In the arrangement of cell components according to the invention, the measuring path between the two electrodes has a stream of carbon dioxide continually flowing over it, the concentration of which fluctuates with the concentration of carbon dioxide in, for example, the anaesthetising gas mixture at the absorber outlet, passes through the membrane of the measuring cell and the measuring path between the electrodes and disappears within the ion exchange resin.

For a better understanding of the invention, and to show how the same can be carried into effect, reference will now be made, by way of example, to the accompying drawing, in which:

Figure 1 is a constructional form of the measuring cell in which the mass of the ion exchange resin contains the second electrode; and

Figure 2 shows a further constructional form wherein two separate metal electrodes are provided.

In Figure 1 the measuring cell is shown partly in section, a diagrammatically illustrated electrical measuring circuit being connected to the cell. This circuit contains an A.C. current source 2 of 24V, an indicating instrument 4 and two terminals 6 with which the two conductors of a cable 8 are connected. The other end of the conductors is connected in each case to a screen-like metal electrode 10 and 12 respectively.

Through a pipe 14 the gas mixture to be supplied to a patient for inhalation anaesthesia issues from an absorber (not shown) filled with soda lime and flows in the direction of an arrow N towards the breathing mask worn by the patient. Constructed in the wall of the pipe 14 is a flange 16 in which the measuring cell is mounted by means of a sealing ring 18, through which the cable 8 is taken.

The measuring cell is formed of a plastics material tube 20 one end of which is closed by a plug 22. At the other end the edge of the plastics material tube 20 is surrounded by a bead 24, e.g. of a cement, which at the same time holds the screen-like electrode 10 in the open end of the plastics material tube 20. On to the annular bead 24 there is drawn a membrane 26 consisting of a sheet of silicone rubber, polyethylene, a co-polymer of tetrafluoroethylene and hexafluoropropylene or polyfluoroethylene, which is held fast on the bead 24 by its own preload or is secured by a rubber ring (not shown).

The cylindrical interior of the plastics material tube 20 is sub-divided by a nylon fabric 28 having a mesh width of 0.1 to 0.2 mm into two portions one of which is filled with an ion exchange resin 30 of granular type. The particles of the granulate preferably have a diameter of 0.3 to 0.6 mm and therefore pass through the screen-like electrode 12, but are retained by the nylon

fabric 28. As the ion exchange resin 30 there can be used an anion/cation mixed bed exchanger whose particles are electrically conductive.

To bring the measuring cell into operation, the interior of the plastics material tube 20 between the gas-permeable but liquid-impermeable membrane 26 and the rear wall of the plug 22 is completely filled with distilled water from which any CO_3 ions are removed by the ion exchange resin 30. As soon as the anaesthetising gas mixture is supplied to the patient through the pipe 14, the gases amongst which there may be the carbon dioxide which is to be detected and measured also pass through the gas-permeable membrane 26 and are dissolved in the water. All gases of the anaesthetising gas mixture to be supplied to the patient with the exception of carbon dioxide do not form ions in the water. As soon as the soda lime of the absorber is exhausted, it is no longer capable of fully absorbing carbon dioxide from the gas mixture which the patient exhales, so that slowly increasing quantities of carbon dioxide pass through the absorber, appear in the pipe 14 and are supplied again to the patient for inhalation.

This carbon dioxide allowed through by the absorber also passes in addition to the other gases through the membrane 26 of the measuring cell and dissolves in the water, with formation of ions. The electrical conductivity of the deionized water, which amounts to about 0.065 to 0.1 uS slowly increases as soon as the absorber is no longer capable of absorbing all the exhaled carbon dioxide. However, slight additions of carbon dioxide in the anaesthetising gas mixture supplied to the patient are not regarded as significant. The threshold of carbon dioxide concentration which is regarded as critical for the patient is 0.2%. This threshold value is shown on the indicating instrument 4, depending on external temperature conditions, about 30 to 60 seconds after the appearance of this CO_2 concentration in the anaesthetising gas mixture, so that the operator is informed that the soda lime filling of the absorber must be renewed without fail. As already indicated, the absorber does not suddenly lose its ability to absorb carbon dioxide from the anaesthetising gas mixture which the patient exhales and which is supplied to him again in the closed circuit, but this process extends over a period of time of at least 15 minutes, so that the patient is supplied for at the most 1 minute with an anaesthetising gas mixture whose carbon dioxide concentration is slightly above 0.2%, which can in practice be regarded as harmless.

The measuring path at which the change in conductivity of the water is scanned, in the constructional form shown in Figure 1, extends between the electrode 10 near the membrane 26 and the edge of the ion exchange resin 30, which is substantially defined by the nylon fabric 28 which retains the mass of ion exchange resin 30. Since ion exchange resins are normally electrically conductive themselves, this mass of resin already constitutes one electrode, so that the construction of the metal electrode 12 as a screen does not seem to be absolutely necessary. But the screen form on the one hand permits an advantageous passage of current from the ion exchange resin 30 to one conductor of the cable 8 and on the other hand permits access of particles of ion exchange resin 30 to the nylon fabric 28 and consequent satisfactory filling of the space available without cavities.

In the constructional form shown in Figure 2 the metal electrode 12 is separated by a space from the ion exchange resin 30. If the ion exchange resin 30 is not very electrically conductive or is not conductive, or if a particularly short and/or precise measuring path is desired, this constructional form shown in Figure 2 is preferred. Figure 2 shows only the measuring cell itself, since the connected electrical measuring circuit and also the pipe 14 conducting the anaesthetising gas mixture can be constructed as shown in Figure 1.

The special advantage of the constructional forms shown in Figures 1 and 2 resides in the co-operation of the ion exchange resin 30 with the measuring path for electrical conductivity, which path extends between the electrodes. The carbon dioxide entering through the membrane 26, which dissolves in water with formation of ions and is uniformly distributed in the mass of water, is fixed by the ion exchange resin so that the latter forms a trap for the carbon dioxide. Consequently an ion flow equilibrium is established in the otherwise stationary liquid (water), and measurement is based upon this.

If the carbon dioxide concentration in the anaesthetising gas mixture should decrease unexpectedly or owing to changing of the absorber filling, the CO_3 ion concentration also decreases in the measuring path, this decrease can be detected at the indicating instrument 4. The possibility of directly reading the decrease in CO_3 ion concentration in a stationary electrolyte (water) constitutes a special feature of the measuring cell according to the invention as far as the operator is concerned.

WHAT WE CLAIM IS:—

1. A device for measuring the concentration of carbon dioxide in a gas mixture which is to be inhaled by a patient, which device comprises a cell the wall of which includes at least one area which is gas-

permeable and liquid-impermeable and which cell includes (a) two electrodes which, in use, are immersed in deionized water and (b) an ion exchange material located at a position remote from the or each area which is gas-permeable and liquid-impermeable, wherein the inner surface of the or each of said areas is in contact with the deionized water and the outer surface of the or each of said areas is such that, in use, it can be contacted by the gas which is to be inhaled by the patient, and wherein one of said two electrodes is positioned between the or each of said areas and the ion exchange material and is insulated from said ion exchange material.

2. A device as claimed in claim 1, wherein said cell is, or is adapted to be, incorporated in a closed circuit respiratory system.

3. A device as claimed in claim 2, wherein said closed circuit respiratory system is an anaesthetising system.

4. A device as claimed in claim 1, 2 or 3, wherein the or each of said areas consists of a membrane made of a plastics foil.

5. A devise as claimed in claim 4, wherein said plastics foil comprises a silicone rubber, a polyethylene, a copolymer of tetrafluoroethylene and hexafluoropropylene, or a polytetrafluoroethylene.

6. A device as claimed in any one of the preceding claims, wherein the other of said two electrodes is constituted by said ion exchange material.

7. A device as claimed in claim 1, 2, 3, 4 or 5, where the other of said two electrodes is located between the first of said two electrodes and the ion exchange material.

8. A device as claimed in any of the preceding claims, wherein said ion exchange material is an ion exchange resin.

9. A device as claimed in any one of the preceding claims, wherein the ion exchange material is held in position within the cell by a fabric mesh the mesh width of which is smaller than the particle size of the ion exchange material.

10. A device as claimed in any one of the preceding claims, wherein the apparatus further comprises means for determining a value which is, or which is proportional to, the electrical conductivity of the liquid which, when the apparatus is in use, is between said two electrodes.

11. A device as claimed in claim 10, wherein said means comprises an alternating-current bridge in one arm of which there is located said cell.

12. A device for monitoring the concentration of carbon dioxide in an anaesthetising gas mixture which comprises a cell of very small volume which is filled with deionized water and which contains two electrodes connectable to an electrical measuring instrument, and which includes at least one membrane of a semipermeable material which at one side is in contact with the anaesthetising gas mixture and at its other side with the deionized water, characterised in that at the side of the cell opposite from the membrane there is arranged a mass of an ion exchange resin and between the membrane and the surface of the ion exchange resin, insulated therefrom, there is arranged one electrode.

13. A device as claimed in claim 12, wherein between the first electrode and the mass of the ion exchange resin there is arranged a further electrode.

14. A device for measuring the concentration of carbon dioxide in a gas mixture which is to be inhaled by a patient, substantially as hereinbefore described with reference to, and as illustrated in, the accompanying drawings.

15. A method for measuring the concentration of carbon dioxide in a gas mixture which is to be inhaled by a patient, substantially as hereinbefore described.

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FIG. 1.

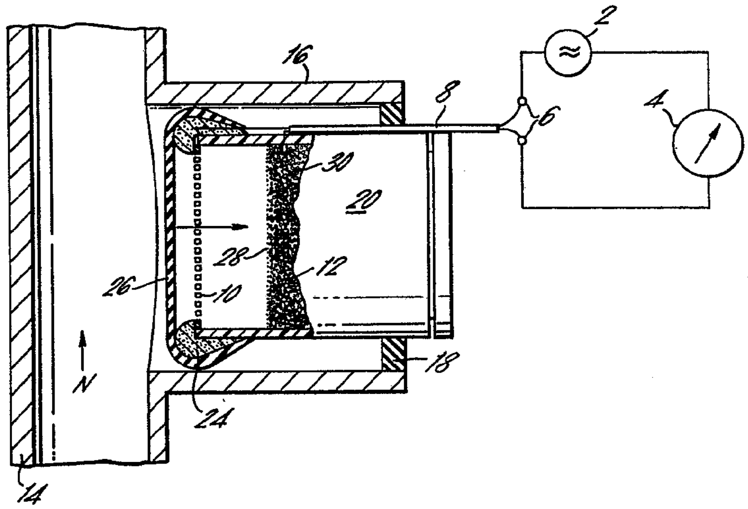

FIG. 2.